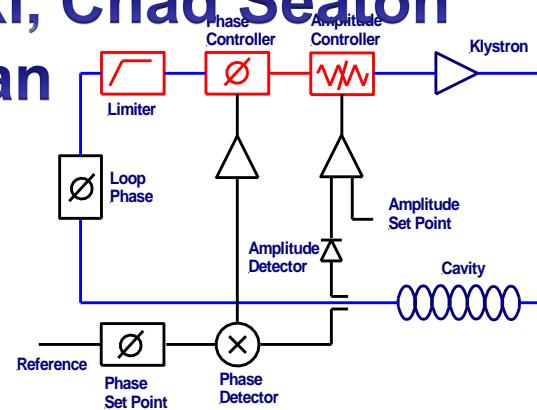
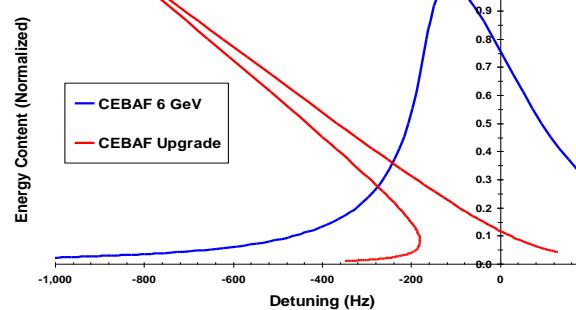


RF Controls at Jefferson Lab

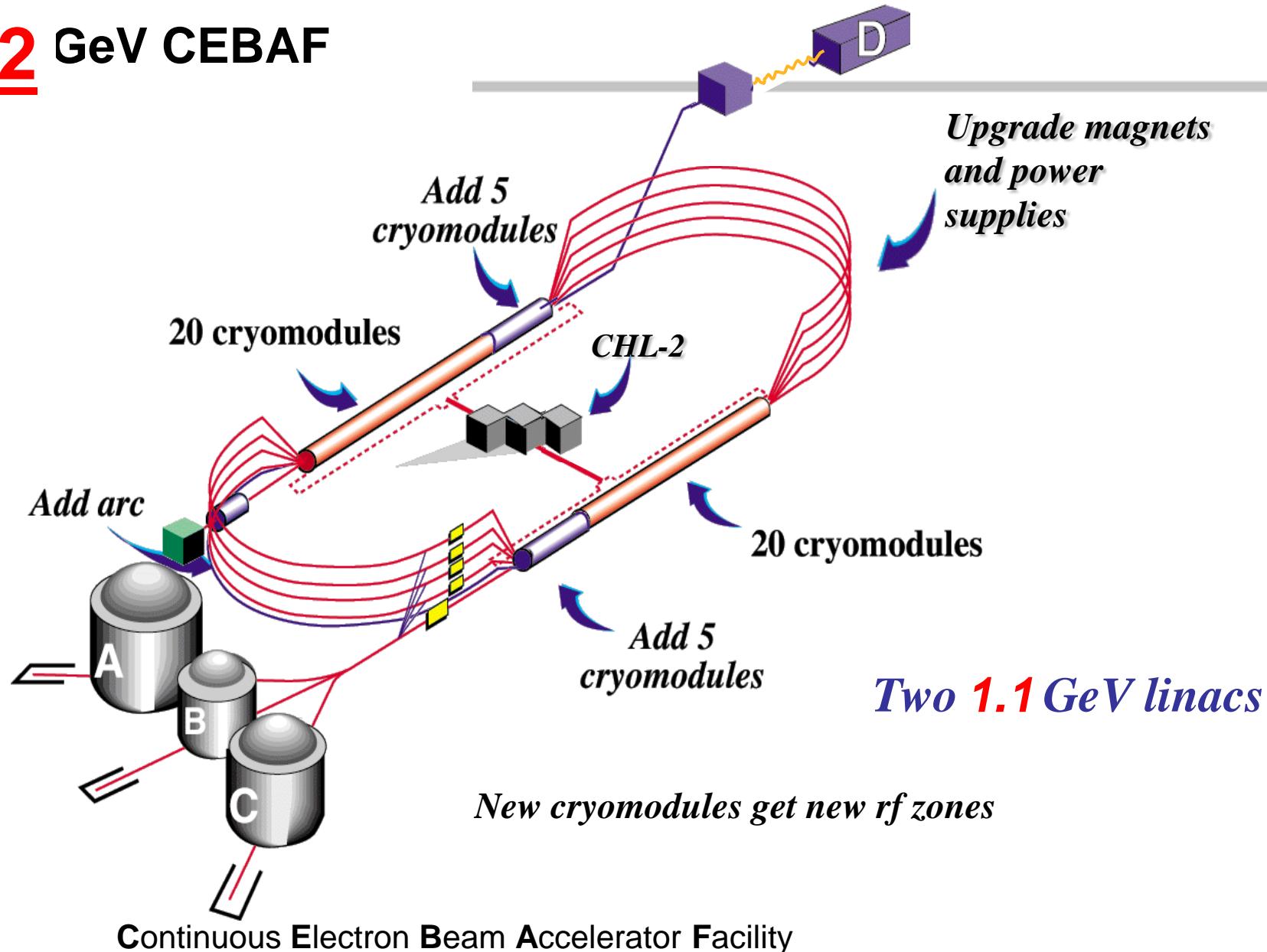
Curt Hovater, Trent Allison, Rama Bachimanchi,
John Musson, Tomasz Plawski, Chad Seaton
and Dave Seidman



Outline

- **JLAB Upgrade**
- **Field Control**
- **Resonance Control & Cavity Interlocks**
- **New RF Activities**

12 GeV CEBAF

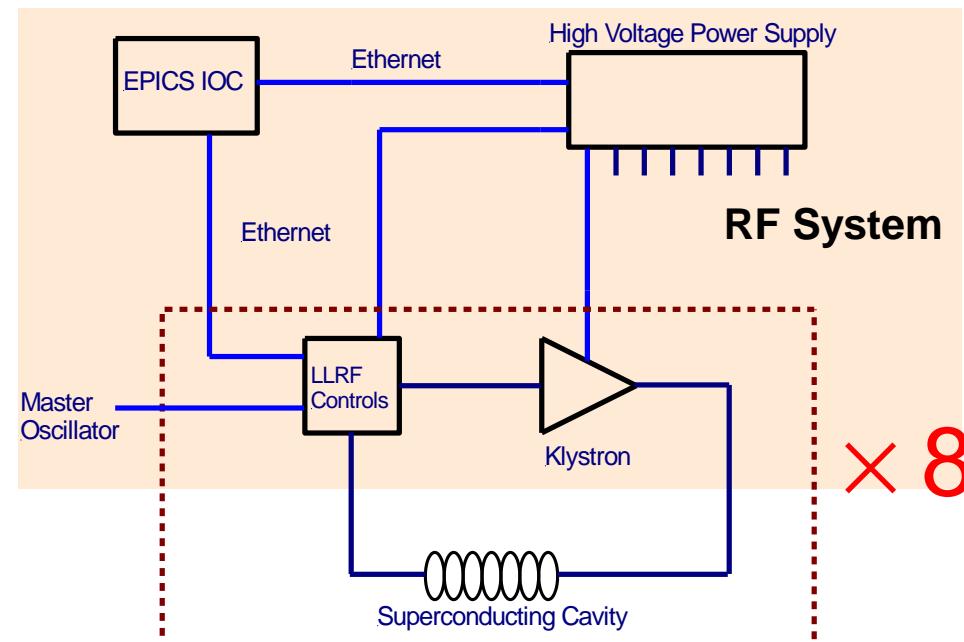


Design Overview: RF Requirements

Key technical parameters: RF

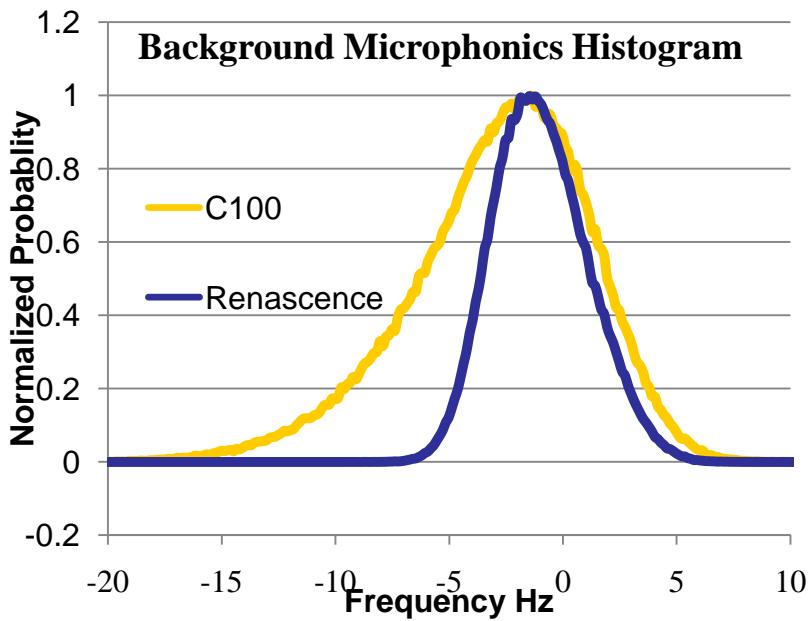
- 10 new zones of RF power for new accelerating structures:
 - Operating Freq.
 - 1497 MHz
 - Operating Gradients Required
 - $>17.5 \text{ MV/m}$
 - Operating RF Power per cavity
 - 13 kW saturated power
 - Control Requirements
 - See table
 - Cavity Q_L
 - $\geq 2 \times 10^7$

		<i>Fast</i> (<1sec)	<i>Slow</i> (>1sec)
Phase Stability (rms)	un-correlated	0.5°	3.0°
Amplitude (rms)	un-correlated	4.5×10^{-4}	NA



Cavity Microphonics

Microphonic Detuning*	Renaissance (stiffened)	C100
RMS Amplitude (Hz)	1.98	3.65
$6\sigma(\text{Hz}) \sim \text{Peak}$	11.9	21.9



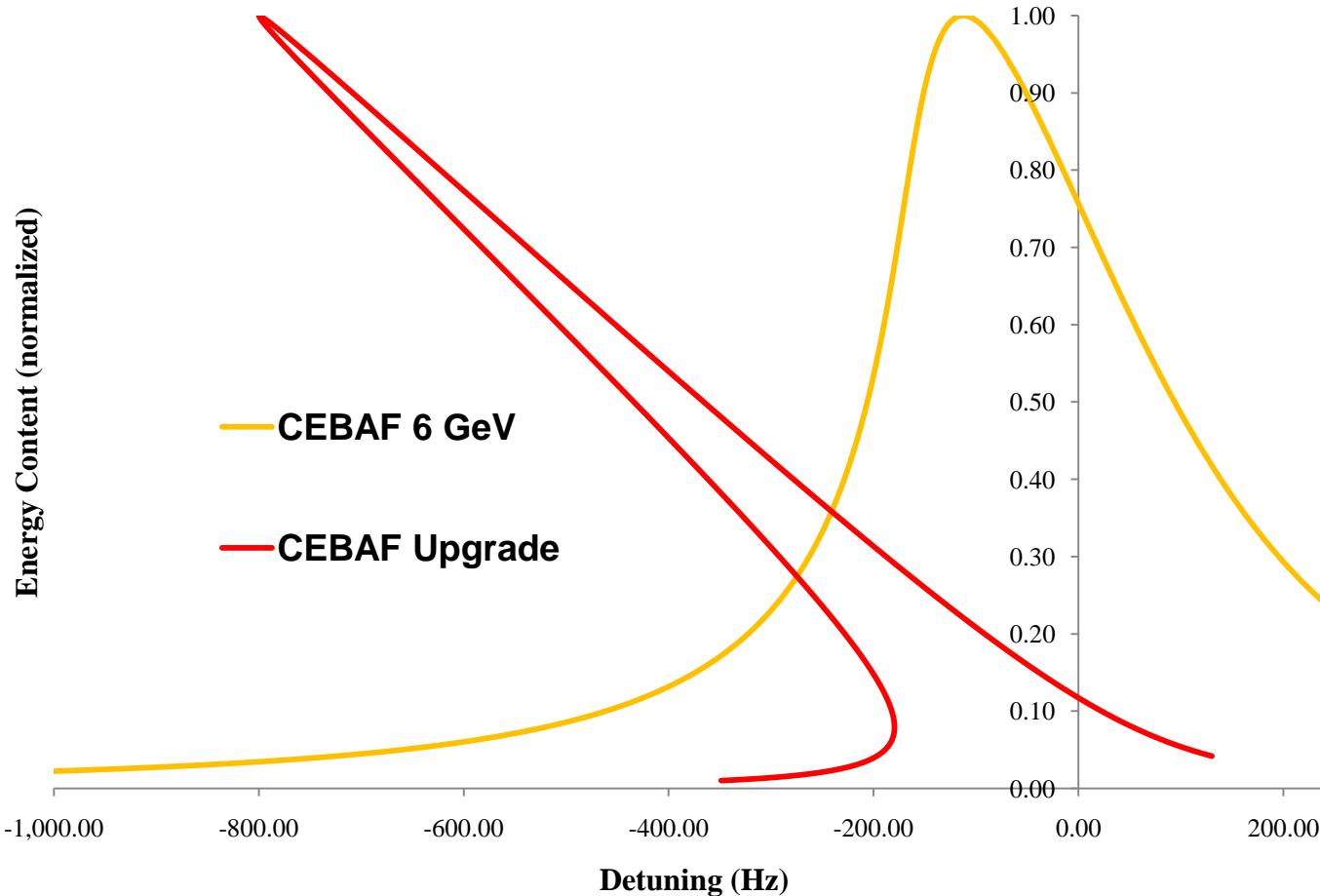
*Data Taken in Same Environment

Microphonic Impact on cavity power operating at 20 MV/m (100 μA of beam)

- **C100 = 5.3 kW**
- **REN = 3.3 kW**

References: 3

Lorentz Detuning



Upgrade Cavities operating at 20 MV/m will see 16 bandwidths of Lorentz detuning

References: 4,5

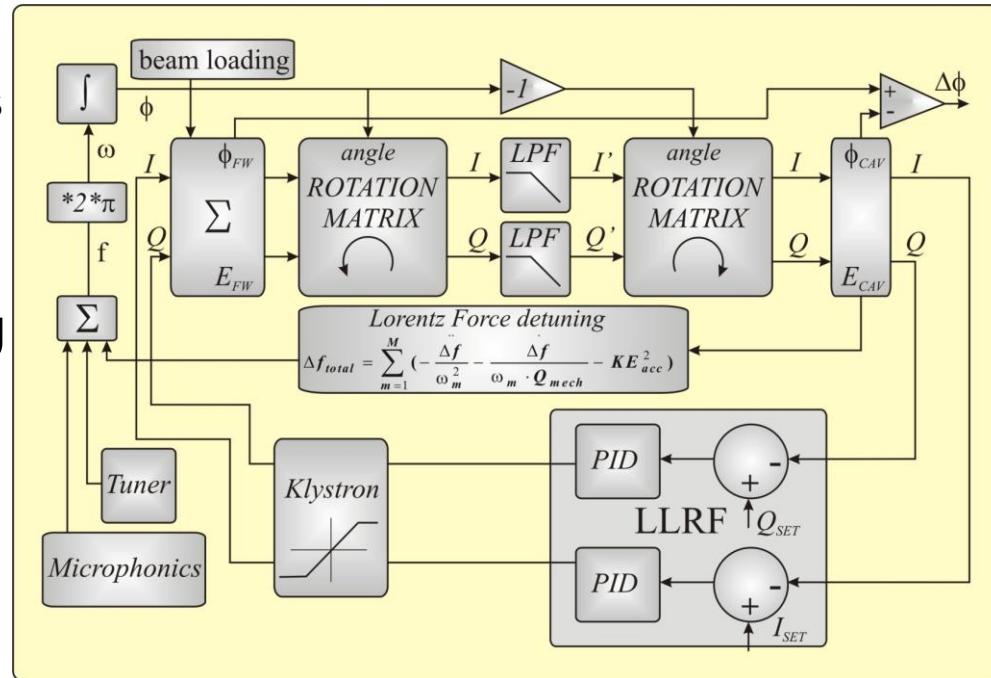
RF System Models: JLAB

Cavity representation is simplified to quadrature components using low pass filter (cavity bandwidth/2).

- Lorentz Force detuning, microphonics and tuners function are incorporated as a frequency modulators.

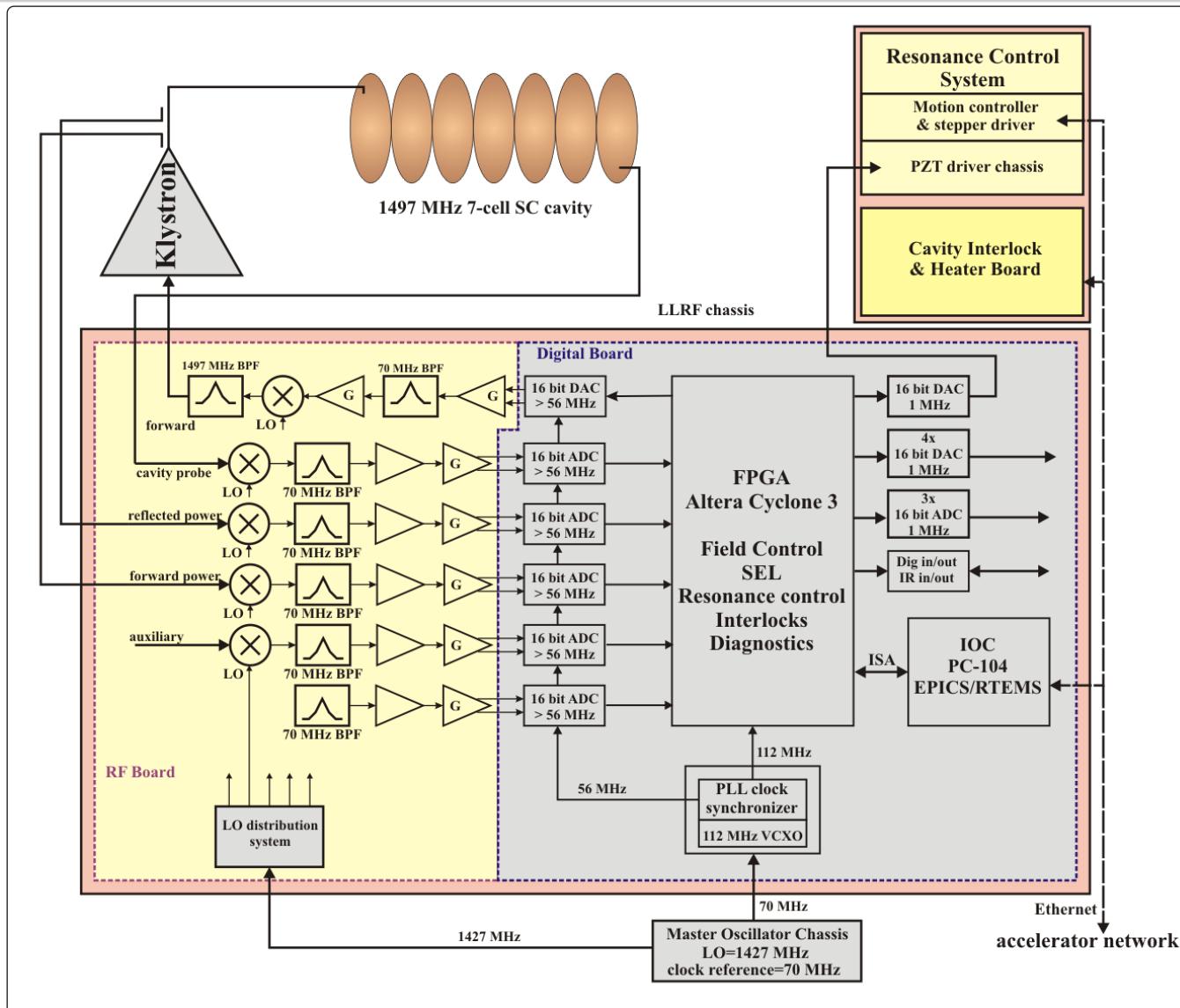
Baseband simulation, mean sampling time for processing can be large (1usec) thus simulation speed is high!

- Rotation matrix for quadrature components to reflect detuning frequency
- Microphonics: External noise generator



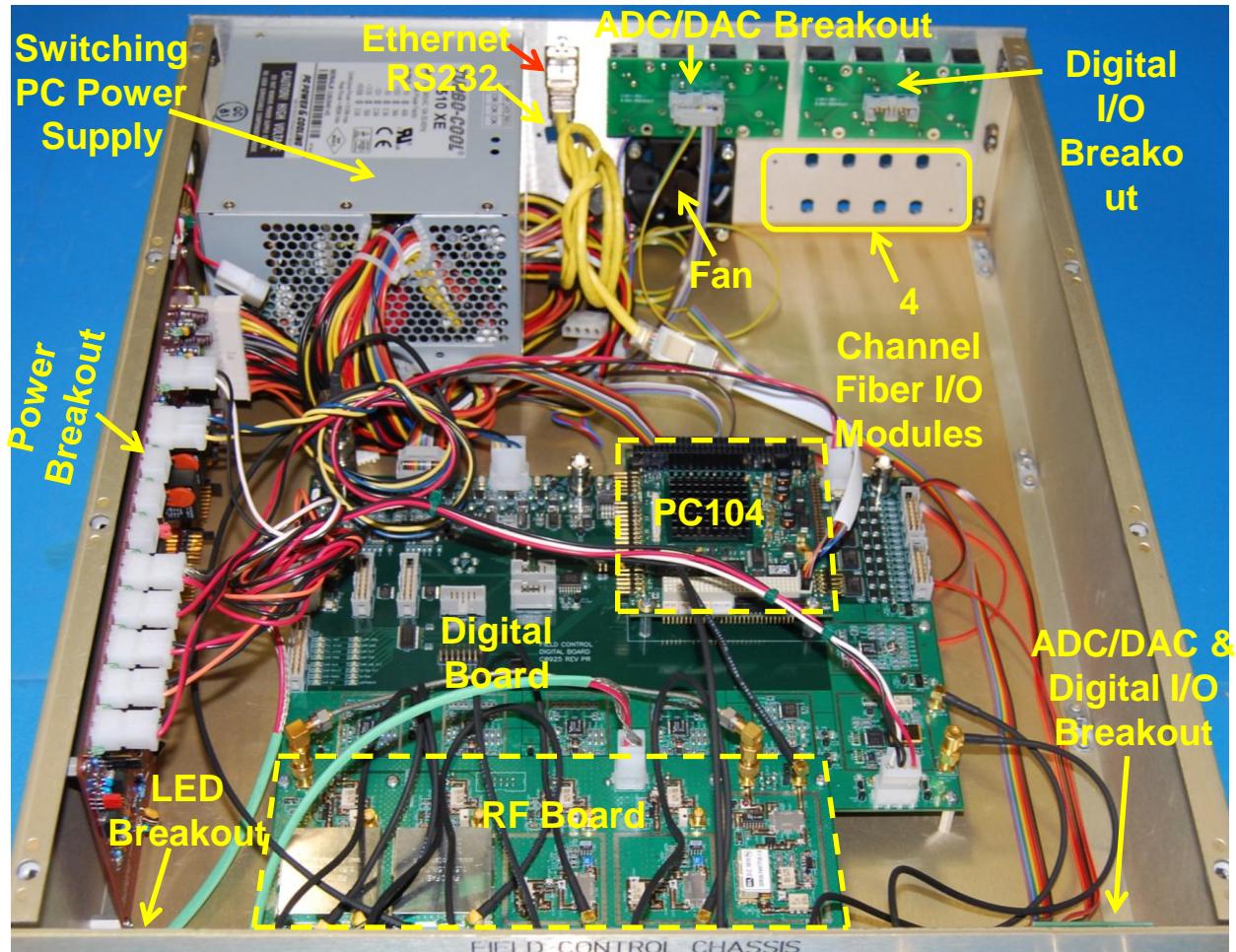
See Tomasz Plawski's talk on Wednesday

JLAB Upgrade RF Control System



Field Control Chassis

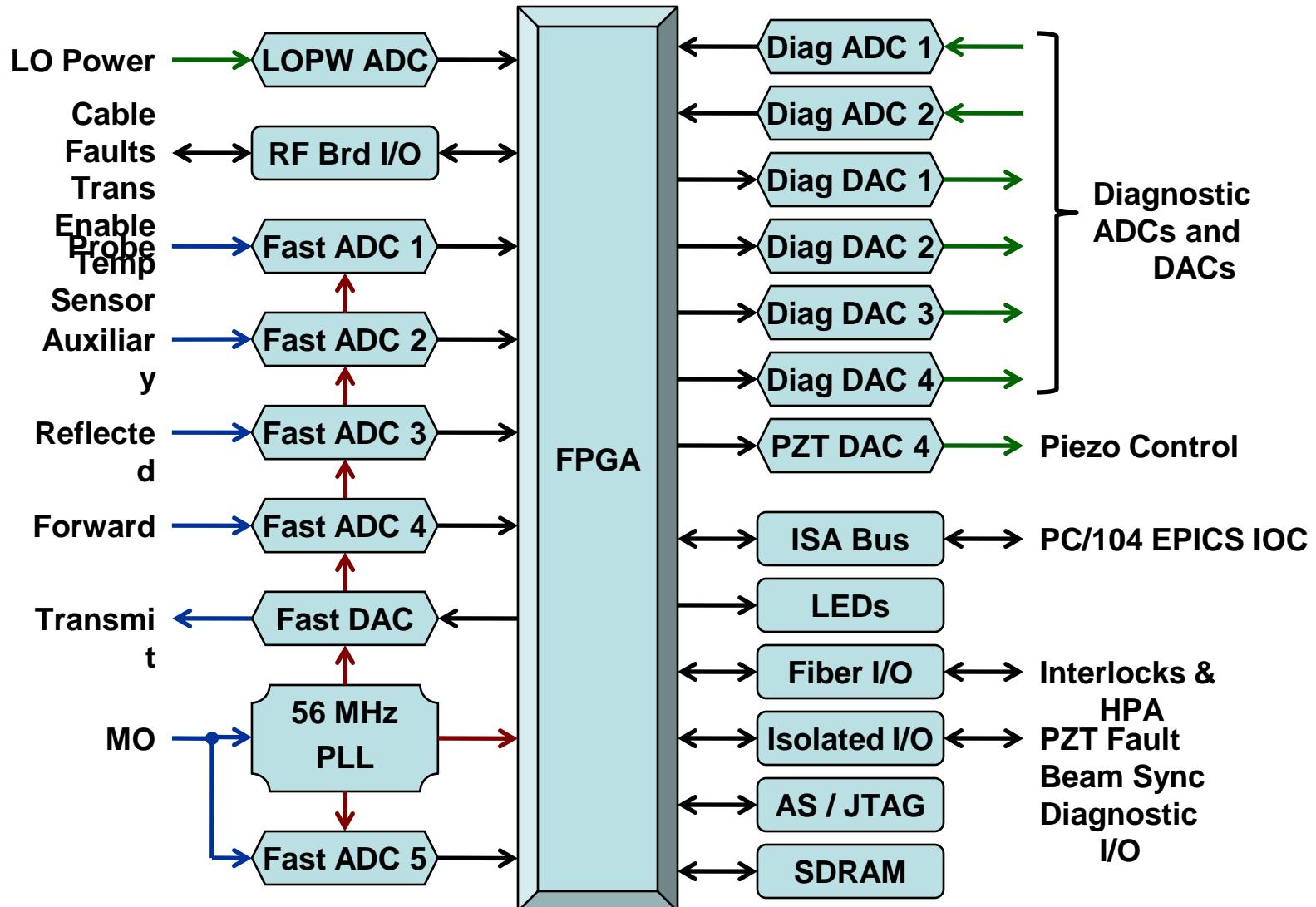
- 3U Chassis Dimension
- “Hot Swap-able”
- Separate RF and Digital boards
- Embedded EPICS IOC (PC104)
- Universal “PC” power supply



Field Control Requirements

Parameter	Value	Imposing Quantities
Frequency	1497 MHz	Existing RF
G*BW (ie. Control Bandwidth)	1 MHz; G >=10 (SRF calcs, JLAB experience), BW ~ 100 kHz	Latency, analog BW, digital BW, sample rate, processing speed, digital resolution
IF and LO	70 MHz and 1427 MHz	Existing IF and LO
Phase Control	0.5 degrees	S/N, C/I, crosstalk, threshold effect, BW, sample rate, digital resolution
Amplitude Control	0.045%	S/N, C/N, BW, crosstalk, sample rate, digital resolution
Dynamic Range	20 dB	Nominal gradient range
Setpoint Resolution	0.1%, 0.1 degree	S/N, digital resolution
Diagnostics	Loopback, Cable Faults, 1MHz ADCs & DACs, Digital I/O, Circular Buffers	Self checking and easy troubleshooting
Thermal Stability	+/- 0.05 dB, 15 ps; 10 °C < T < 40 °C (0.002 dB / °C; 0.5 ps / °C)	Stable over service building temperatures
External Interfaces	HPA, Interlocks, Resonance Control	HV/RF Enable, Quench, Detune Angle

Digital Board Block Diagram



Algorithms and Software

Self Excited Loop (SEL)

- SEL successfully Tested on HTB June 2008
- Hybrid SEL/IQ lock tested April 2009 on Cavity Emulator (See Thursday Talk)

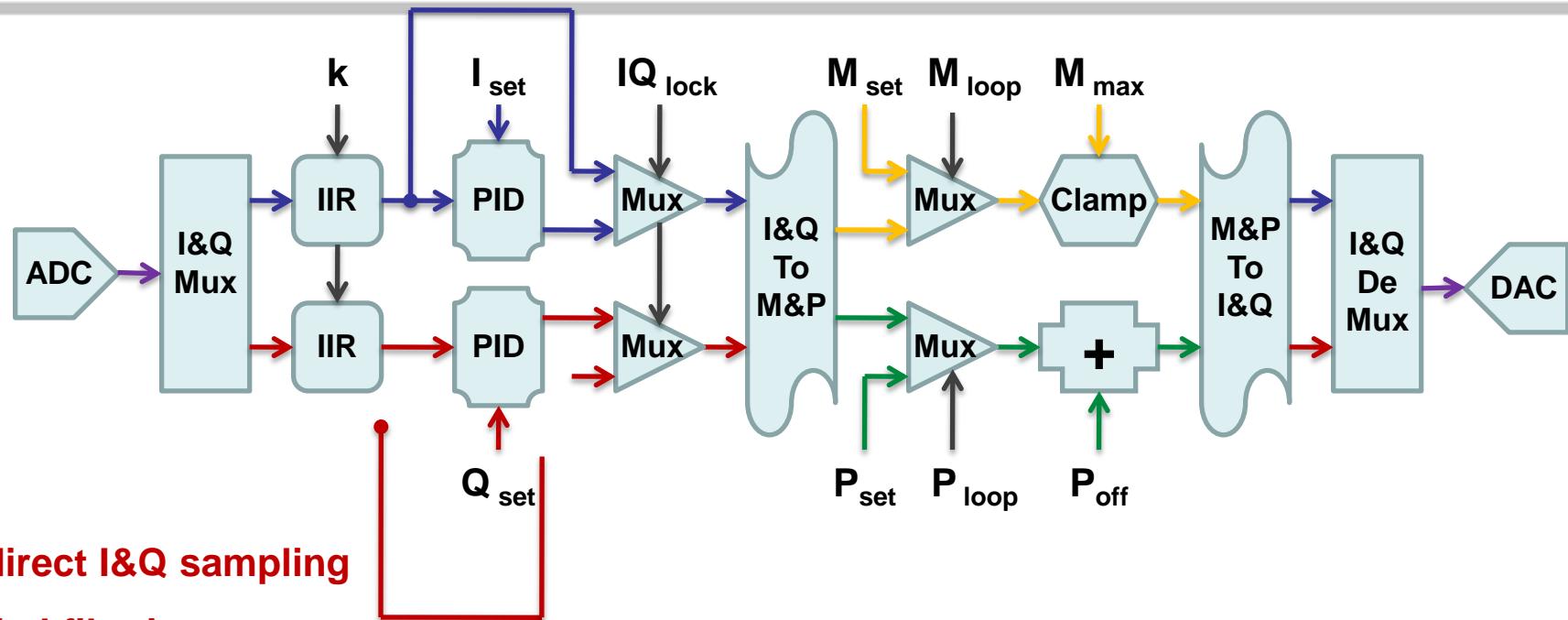
Generator Driven Resonator (GDR- I/Q)

- Algorithm has been installed and working on the normal conducting cavities since 2005. Includes reference feature to find absolute phase in advent of power loss.
- Algorithm has been tested and met field control specification on HTB (non stiffened cavities).

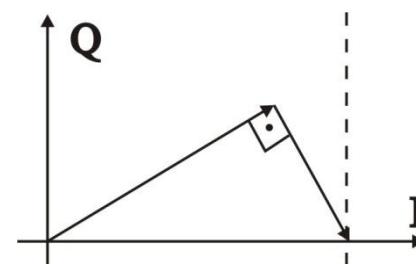
EPICS Interface

- Expert EPICS screens have been made and tested for Field Control, Resonance Control and Cavity interlocks.

Signal Processing Block Diagram: SEL/IQ

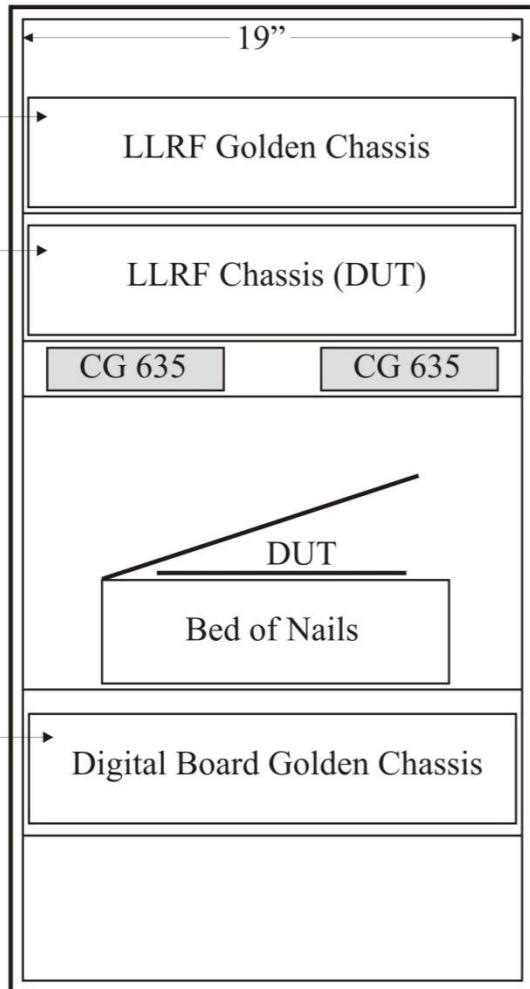


- IF direct I&Q sampling
 - digital filtering
 - I&Q to Phase&Magnitude - COordinate Rotation Dligital Computer (CORDIC)
 - SEL mode
 - Microphonics Compensation
 - single DAC generating IF signal
- See Trent Allison's talk on Thursday

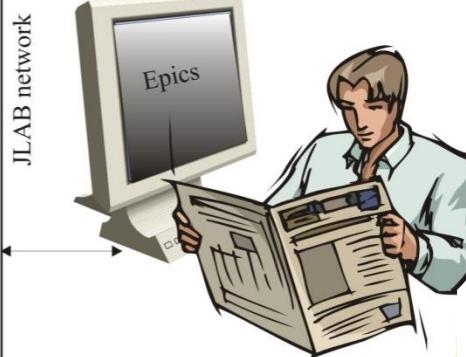


RF- Digital Board Test Stand

LLRF - TEST STAND



- Automate as much as possible
- RF Board Testing
 - LLRF Golden Chassis
 - LLRF Chassis (DUT)
 - CG 635: 70/1427 MHz sources



- Digital Board Testing
 - Bed of Nails
 - Digital Board Golden Chassis
 - CG 635: 70 MHz source

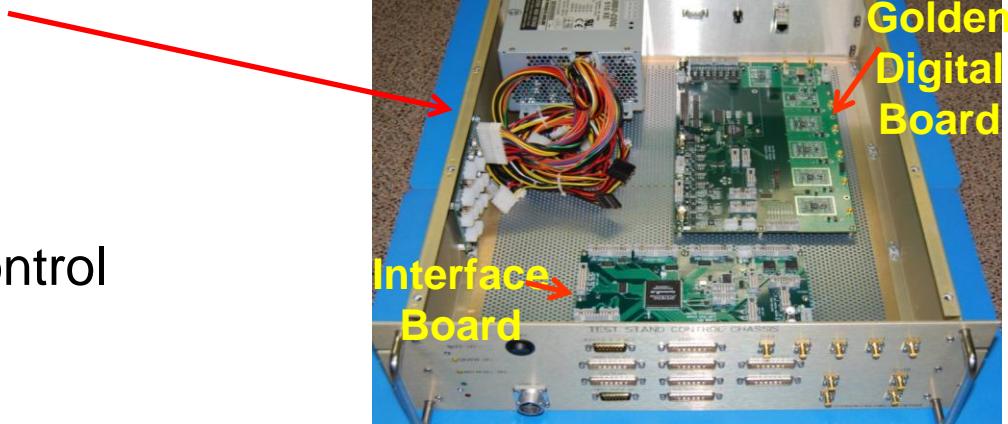
RF- Digital Board Test Stand

- Combines digital and RF board tests.
- Quick automated “go” “no-go” test
- RF and Digital boards are paired and calibrated together
- Ready for chassis assembly



Digital Board “Bed of Nails”Test Fixture

- Digital Board Test Stand Control Chassis
 - Interface Board
 - Golden Digital Board
 - PC104 with EPICS control



Cavity Resonance Control & Interlocks

Resonance System

Stepper Motor:

- A chassis was installed and operating on the evolutionary cryomodule Renascence.
- Separate Chassis: one /zone

Piezo Tuner:

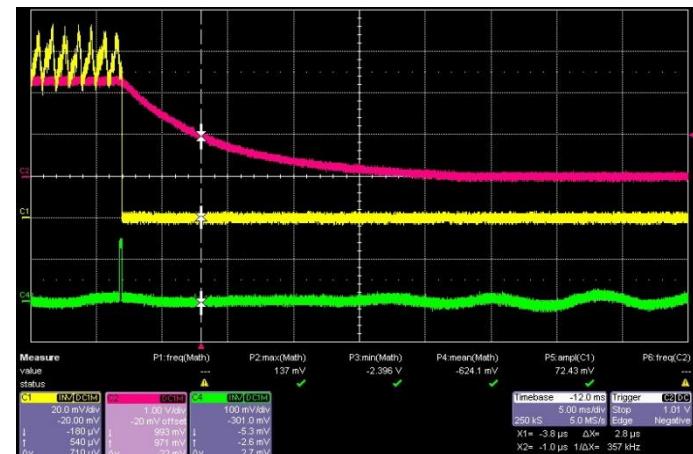
- Design has been tested on the HTB cavities
- Separate Chassis: one /zone



Cavity Interlocks

Interlocks:

- Arc, IR, Vacuum (waveguide & beam line), Quench, He Pressure/Level
- Interlock chassis successfully tested with FC chassis
- Separate Chassis: one /zone



O'Scope Picture of ARC test

Cavity Resonance Control

Goals of a CEBAF resonance control system

Must: Keep the cavity as close as possible to the reference frequency, ultimately minimizing forward power.

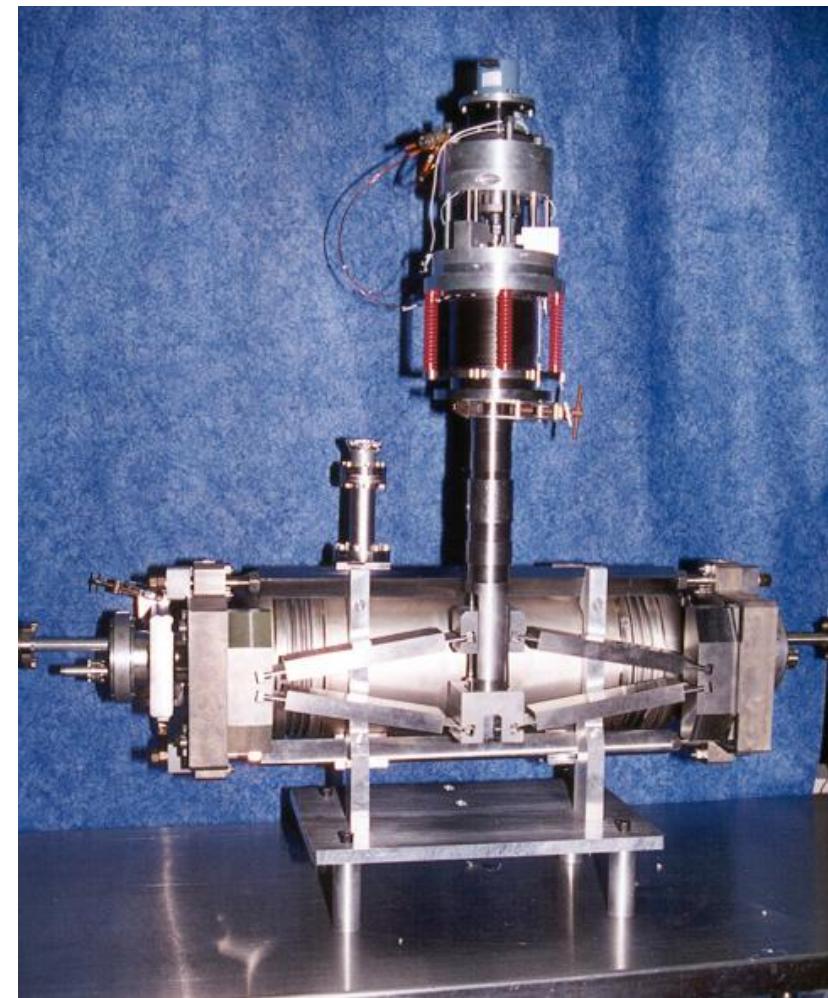
Must: Reliable and maintainable

Like: Minimize microphonics to assist electronic feedback

Tuning Methods

- Stepper Motor: speed < 1 Hz
- Piezo tuner: speed > 1 Hz

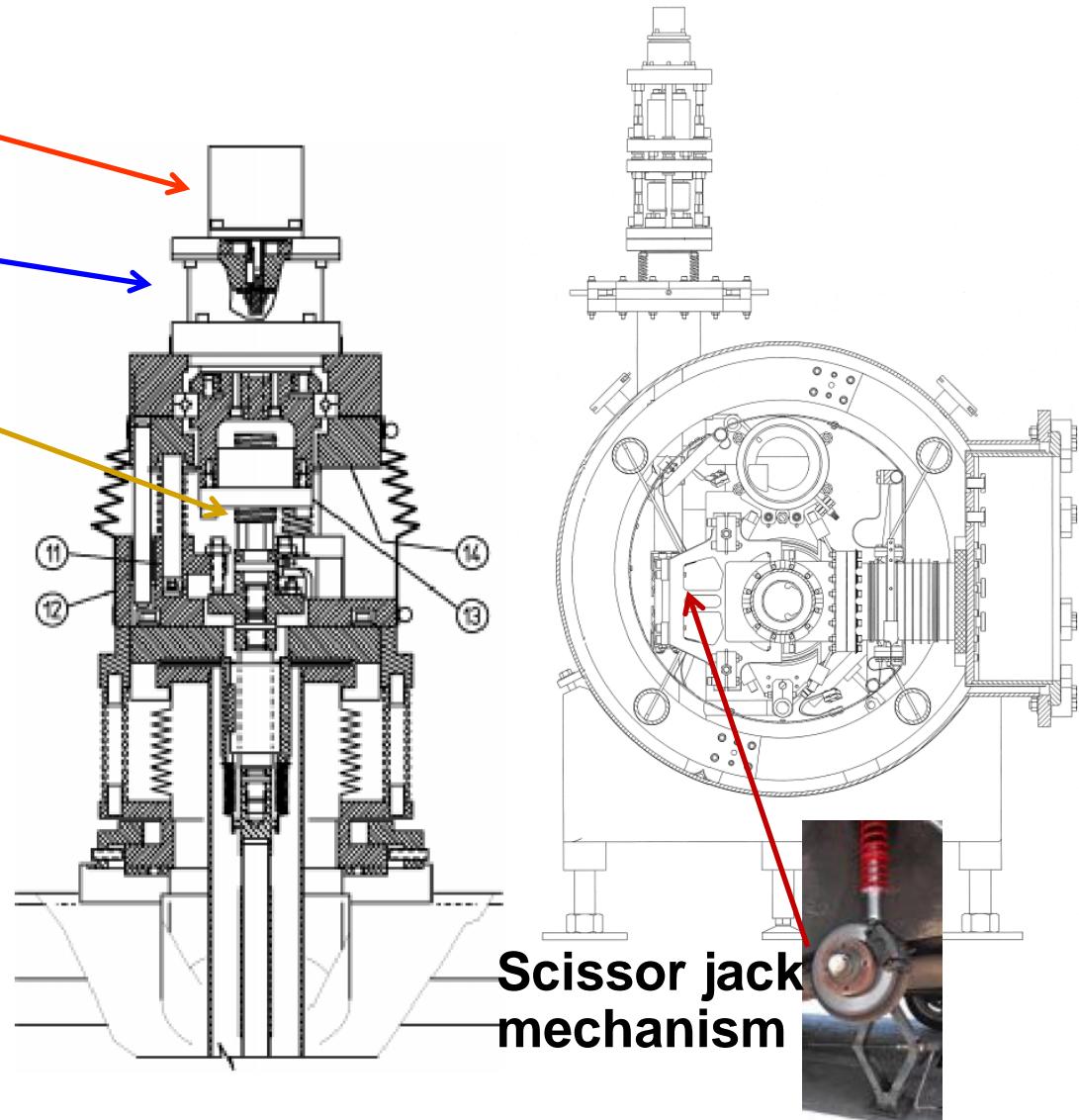
References: 19



Prototype tuner for CEBAF Upgrade

Warm Drive Components and Cross Section of Upgrade CM

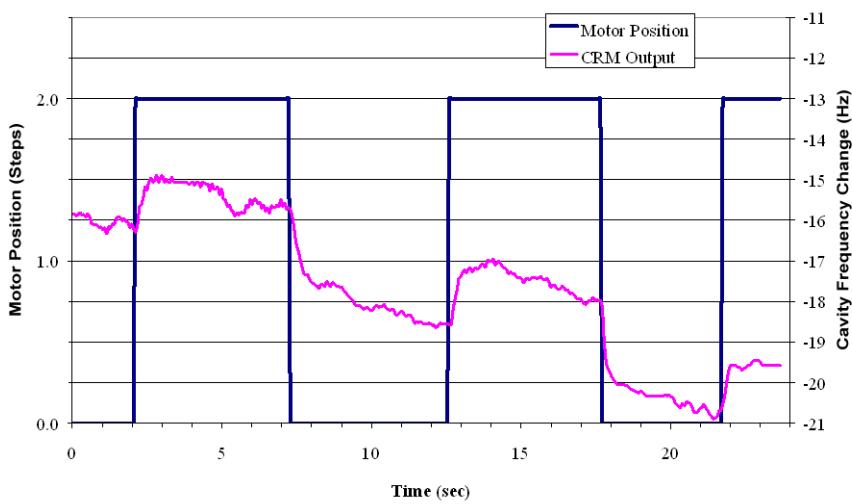
- Stepper Motor
 - 200 step/rev
 - 300 RPM
- Harmonic Drive
 - Gear Reduction = 80:1
- Low voltage piezo
 - 150 V
 - 50 μm stroke
- Ball screw
 - Lead = 4 mm
 - Pitch = 25.75 mm
- Bellows/slides
 - axial thermal contraction



References: 19

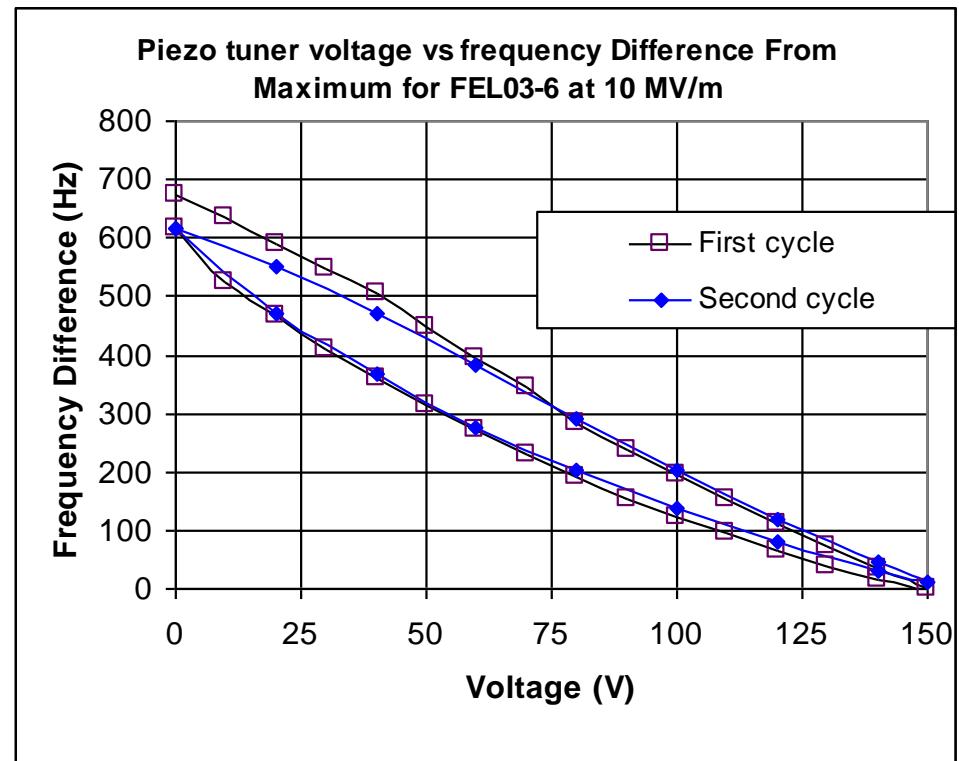
CEBAF Upgrade Coarse & Fine Tuner

Stepper Motor



Resolution/Deadband < 2 Hz
Drift due to Helium pressure fluctuations

PZT



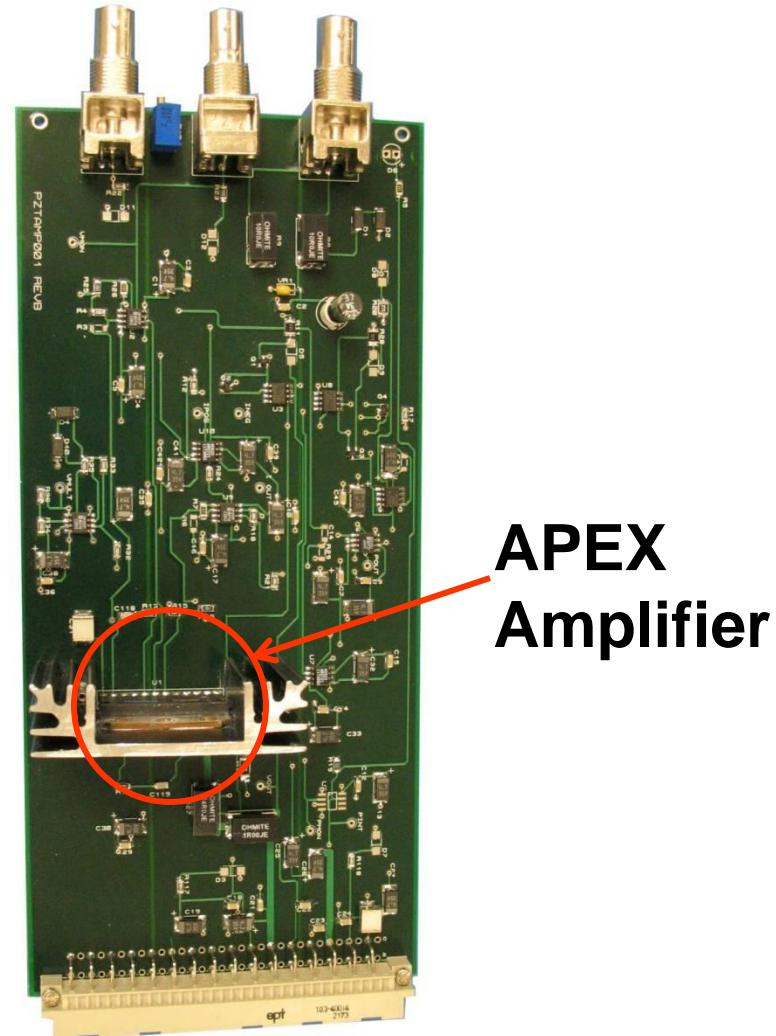
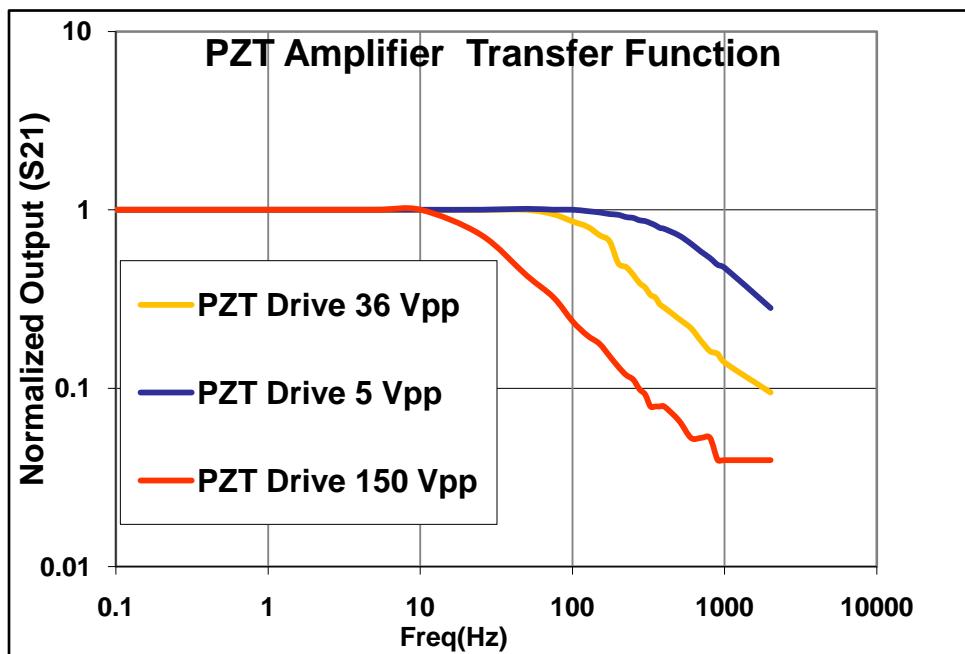
Resolution (Piezo Hysteresis)

References: 3

JLAB Piezo Tuner

Features

- Commercial APEX piezo driver amplifier.
- 0 to 150 V at 50 mA.
- Bandwidth (FS): 10 Hz
- Packaging: 3U Eurocard x8

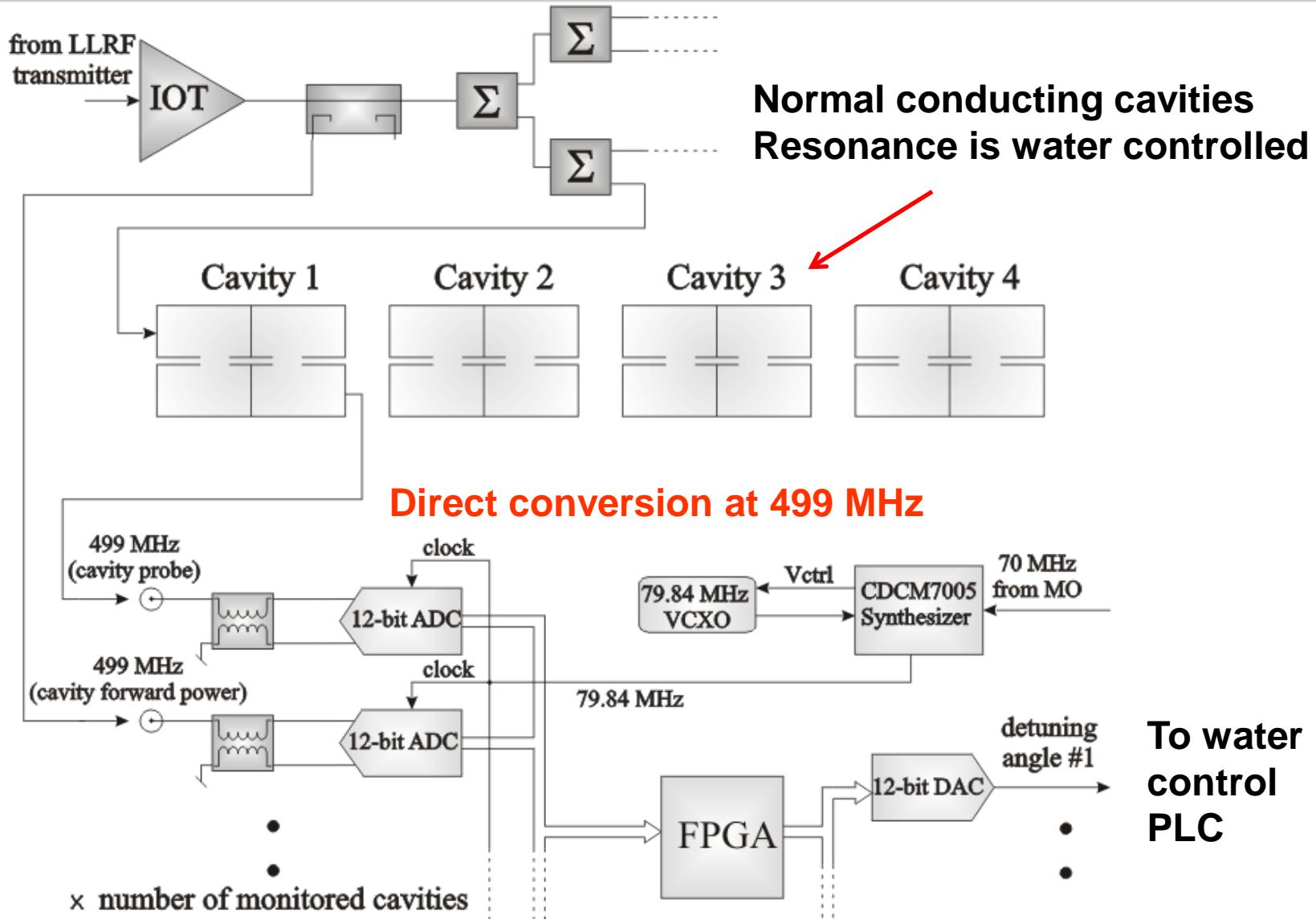


12 GeV RF Controls Schedule

- Construction
 - Procurements begin October 2009 and continue through 2010
 - Fabrication and assembly begin in January 2010 and continue through 2012
- Installation:
 - May 2011 – November 2011: 6 month CEBAF Down
 - May 2012 – May 2013: 12 month CEBAF Down

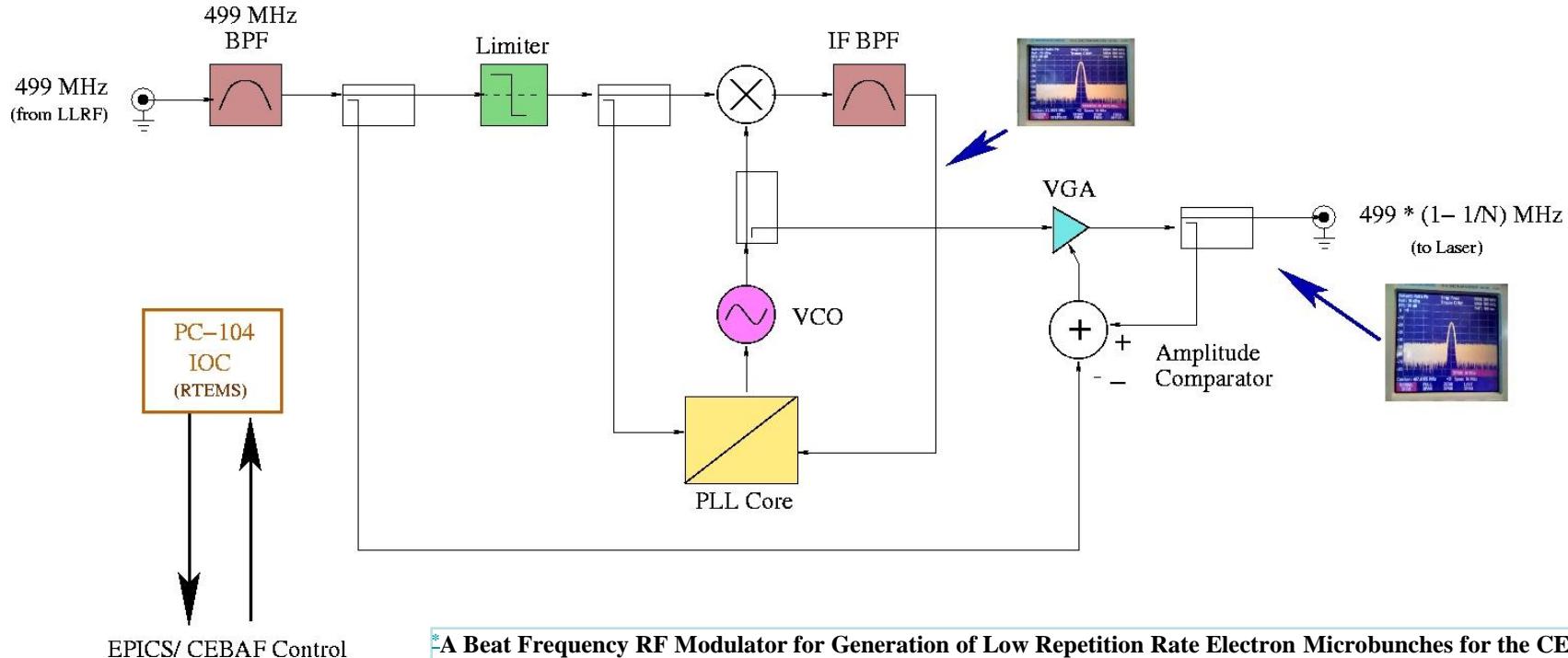
At the end of each down the RF system is ready for cryomodule commissioning
- Accelerator Commissioning: June 2013

RF Separator Resonance Control



Beat Frequency Generator

- Needed a way to create empty buckets for a variety of Nuclear physics reasons.
- Typical bunch spacing is 499 MHz or 2 ns
- A beat-frequency (aliased) signal is created when the injector is run at a slightly different frequency, and analyzed by the 499 MHz Chopper system.
- The resulting beam fills every Nth bucket, creating the desired delay in 2 ns increments.



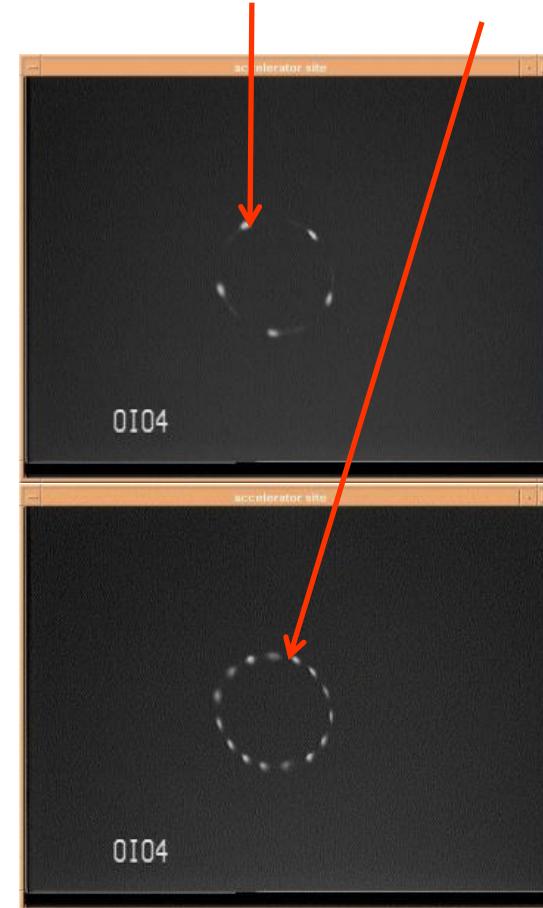
A Beat Frequency RF Modulator for Generation of Low Repetition Rate Electron Microbunches for the CEBAF Polarized Source J. Musson[#], J. Grames, J. Hansknecht, R. Kazimi, M. Poelker
Proceedings of PAC07, Albuquerque, New Mexico, USA

Beat Frequency Generator

Selected Values for N

Bunch Spacing (nsec)	N	Laser Frequency (MHz)	Bunch Frequency (MHz)
10.0	5	399.2	99.8
16.0	8	436.625	62.375
20.0	10	449.10	49.9
32.1	16	467.8125	31.1875
40.1	20	474.05	24.95
50.1	25	479.04	19.96

Beam Chopping Image



RF Controls at Jefferson Lab

Questions?